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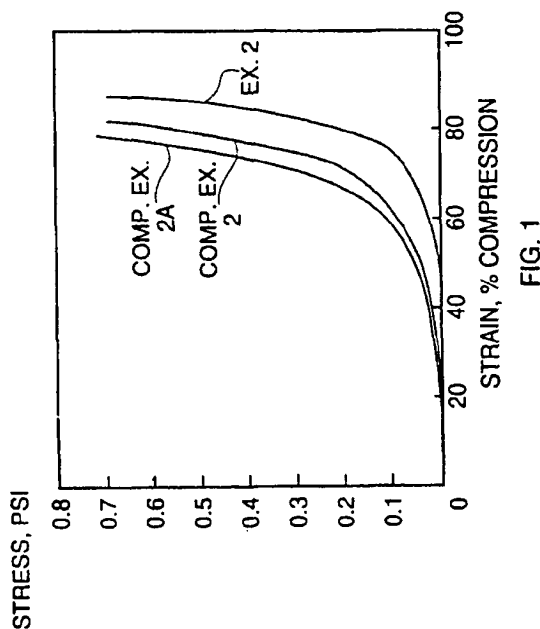
(54) Thin clothing insulation with improved draping and comfort characteristics.

(57) The invention is directed to a synthetic fiber thermal insulator material in the form of a flexible, conformable, sheet-like structure, which structure comprises an assemblage of :

(a) from about 50 to 100% by weight of slickened, spun and drawn, crimped staple polymeric microfibers having a diameter of from about 3 to 12 microns ;

(b) from about 0 to 30% by weight of unslickened, spun and drawn, crimped staple polymeric microfibers having a diameter of from about 3 to 12 microns ; and

(c) from about 0 to 30% by weight of synthetic polymeric macrofibers having a diameter of from about 12 to 50 microns, wherein at least some of the fibers are bonded or mechanically interconnected one to another, and wherein the resultant fiber assemblage has a thermomechanical parameter T greater than about 0.25 (m<sup>2</sup>·K/W·m)/(mN·cm).



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FIELD OF THE INVENTION

This invention relates to thermally insulating, textile-based material. More particularly this invention relates to thin, light-weight, flexible and conformable, thermally efficient insulation systems which can be achieved by the use of assemblies of fine fibers.

BACKGROUND OF THE INVENTION

A synthetic-fiber based thermal insulator tradenamed THINSULATE® has found wide market acceptance for applications in which the loft and bulk of traditional insulation are undesirable. Typical of such applications are: gloves, boots, slim-line ski wear, and dress coats. The synthetic fiber from which THINSULATE is formed is a melt-blown polyolefin microfiber that is characterized by relatively low tensile and bending strengths and lack of crimp. As the polyolefin microfibers are melt-blown they are deposited on a moving apron to form the THINSULATE web. Low fiber strength, lack of crimp, and the tackiness of the melt-blown fibers result in a web that is, inevitably, thin and dense (typical density is about 3 lb/ft<sup>3</sup>). For some applications, this density is too great, and crimped, bulking macrofibers are added to the web to decrease the density. The inclusion of crimped bulking fibers to decrease density (or increase loft) in a melt-blown microfibrinous web is disclosed in Hauser, U.S. Patent No. 4,118,531.

In spite of THINSULATE's wide commercial acceptance, garment designers, manufacturers, and consumers object to the material's stiffness and resistance to draping. These deficiencies sometimes preclude the use of THINSULATE, but more frequently they lead to the use of thinner THINSULATE webs to obtain acceptably low stiffness and adequate drapability. The loss of insulating performance that accompanies such a compromise is, however, very counterproductive.

Donovan, U.S. Patent No. 4,588,635 describes and claims a synthetic fiber batt thermal insulator material which comprises a blend of spun and drawn crimped, staple polymeric microfibers having a diameter of from 3 to 12 microns and polymeric staple macrofibers having a diameter of from more than 12 up to 50 microns. The batt has a density of from 0.2 to 0.6 lb/ft<sup>3</sup>. This material approaches, and in some cases exceeds, the thermal insulating properties of natural down.

From a mechanical standpoint, it is a matter of experience that extremely fine fibers suffer from deficiencies of rigidity and strength that make them difficult to produce, manipulate, and use. Compressional properties of such a synthetic insulator material are enhanced by blending in some fibers of larger diameter, but an increase in the large fiber component will seriously reduce the thermal insulating properties overall.

According to U.S. Patent No. 4,992,327 a synthetic fiber thermal insulator material in the form of a cohesive fiber structure comprises an assemblage of polymeric microfibers having a diameter of from 3 to 12 microns and polymeric macrofibers having a diameter of from 12 to 50 microns. At least some of the fibers are bonded at their contact points, the bonding being such that the density of the resultant structure is within the range of from 0.2 to 1.0 lb/ft<sup>3</sup>.

OBJECTS OF THE INVENTION

It is an object of the invention to provide a novel, thin light-weight, drapable insulating material with improved thermo-mechanical properties.

It is also an object of the invention to provide a synthetic fiber thermal insulator material comprising an assemblage of:

- (a) from about 50 to 100% by weight of slickened, spun and drawn, crimped staple polymeric microfibers having a diameter of from about 3 to 12 microns;
- (b) from about 0 to 30% by weight of unslickened, spun and drawn, crimped staple polymeric microfibers having a diameter of from about 3 to 12 microns; and
- (c) from about 0 to 30% by weight of synthetic polymeric macrofibers having a diameter of from about 12 to 50 microns,

wherein at least some of the fibers are bonded or mechanically interconnected one to another, the density of the resultant structure is in the range of from about 0.5 to 4.0 lb/ft<sup>3</sup>, and the thermomechanical parameter T is greater than about 0.25 (m<sup>2</sup>-K/W-m)/(mN-cm).

These and other objects of the invention will become more apparent in the description below.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a graphic representation of compressional stress vs. strain for an Example of the invention and

for two Comparative Examples;

Figs. 2 and 3 are photomicrographs of an Example of the invention; and

Figs. 4 and 5 are photomicrographs of a Comparative Example.

## DETAILED DESCRIPTION OF THE INVENTION

The invention described herein provides an alternative to THINSULATE that has equal or better insulating performance and greatly improved bending and draping characteristics. This alternative insulator is comprised of either (1) a fiber mixture that includes a large fraction of spun and drawn, staple microfibers or (2) only spun and drawn staple microfibers. Some or all of the spun and drawn microfibers may be treated with a lubricating, water repellent finish, often referred to as a slickener. The spun and drawn microfibers of the invention are, in contrast to the melt-blown microfibers of THINSULATE, (1) crimped, (2) elastic in bending, i.e., "springy", (3) relatively mobile and (4) optionally, lubricated. These differences provide the webs of the invention with greater loft, a much softer hand, and less resistance to bending. Moreover, the new webs have improved drapability and improved insulating efficiency on a weight basis.

Thus, the invention is a unique combination of excellent thermal and mechanical performance. An appropriate measure of thermal performance is the thermal resistance per unit thickness ( $R/\text{unit thickness}$ ), which normalizes the experimental data to account for specimen-to-specimen differences in thickness. A high value of this parameter denotes a superior level of thermal performance. The bending and drapability of insulating material is indicated by its flexural rigidity. A low value of this parameter is associated with improved conformability, which is an asset during the manufacture of and in the use of insulated garments. An appropriate parameter to use to express a combination of these two properties is the thermomechanical parameter  $T$ , defined as follows:

$$T = \frac{(\text{thermal resistance/unit thickness})}{(\text{flexural rigidity/unit width})}$$

This thermomechanical parameter  $T$  describes the ability of the insulator assembly to provide thermal insulation, while at the same time maintaining flexibility and conformability. Moreover, the thermomechanical parameter  $T$  represents a meritorious value for an insulating material wherein high levels of thermal insulation and conformability and drapability are required. Superior performance in this regard is represented by a high value of  $T$ .

The thermomechanical parameter  $T$  can be maximized by increasing the thermal resistance and/or decreasing the flexural rigidity, and both of these individual parameters have natural limits for fiber assemblies. The absolute minimum value of thermal conductivity that can be achieved in a fiber assembly is that of a layer of still air of the same thickness. In the practical range of fiber insulation densities, the conductivity approaches this value most closely at around densities of about 1.0 lb/ft<sup>3</sup>. Heat transfer increases at lower densities as a result of an increased radiation component and at higher densities as a result of increased conduction through the fiber material. Since there is a reciprocal relationship between apparent thermal conductivity and thermal resistance, the thermal resistance shows a maximum over this density range, and this represents the optimal thermal performance on a density-normalized basis.

The minimum flexural rigidity that can be achieved in any fiber assembly is the sum of the flexural rigidities of the individual fiber elements, with the orientation of the fibers being taken into proper account. Any interaction between the fibers that inhibits complete freedom of movement so that the constituent fibers are not free to act independently increases the flexural rigidity of the assembly, and the degree of interaction, and, hence, the stiffness, will normally increase rapidly with increasing density. Therefore, the most conformable insulator will be that which establishes and preserves the maximum degree of individuality of the fiber components, consistent with an adequate level of assembly integrity.

Applicants have discovered a combination of fiber selection and batt construction that provides a relatively thin thermal insulator with (1) unusually high insulating efficiency and (2) excellent conformability and drapability characteristics. This surprising and desirable result has not before been available and is characterized by a high value of  $T$ , the thermomechanical parameter. More particularly, the insulating material of the invention can be described as an assemblage of:

- (a) from about 50 to 100% by weight of slickened, spun and drawn, crimped staple polymeric microfibers having a diameter of from about 3 to 12 microns;
- (b) from about 0 to 30% by weight of unslickened, spun and drawn, crimped staple polymeric microfibers having a diameter of from about 3 to 12 microns; and
- (c) from about 0 to 30% by weight of synthetic polymeric macrofibers having a diameter of from about 12 to 50 microns.

Element (c) may comprise single component fibers or multicomponent, preferably bicomponent, fibers, where

the single component or at least one component has a melting point lower than that of the microfibers of one or both of elements (a) and (b).

It is preferred that the resultant fiber assemblage has an apparent thermal conductivity  $k$  measured by the plate to plate method according to ASTM C518 with a heat flow down of less than 0.4 Btu-in/hr-ft<sup>2</sup>-°F. Also, the resultant fiber assemblage must have a density of from about 0.5 to 4.0 lb/ft<sup>3</sup> and a thermo-mechanical parameter  $T$  of greater than about 0.25, preferably from about 0.30 to 50, (m<sup>2</sup>-K/W·m)/(mN·cm).

The invention also includes a method of forming useful thermal insulating material, which comprises the steps of

- (1) forming an assemblage of elements (a), (b), and (c) described above;
- (2) shaping the assemblage so formed; and
- (3) effecting connectivity between some of the fibers at their contact points.

Microfibers and macrofibers for use in the present invention may be manufactured from polyester, nylon, rayon, acetate, acrylic, modacrylic, polyolefins, spandex, polyaramids, polyimides, fluorocarbons, polybenzimidazoles, polyvinylalcohols, polydiacetylenes, polyetherketones, polyimidazoles, and phenylene sulfide polymers such as those commercially available under the trade name RYTON.

In general it is preferred that the microfibers are drawn following extrusion to impart tensile modulus of at least 70 grams per denier.

The macrofibers may be all the same or different material and may be either the same as the microfibers or different. In an advantageous embodiment of the invention the microfibers and the macrofibers are formed from polyesters.

The macrofibers can be monofibers, i.e., fibers having a substantially uniform structure, or they may be multi-component fibers having a moiety to facilitate fiber to fiber bonding. The macrofiber may be a fiber mixture in which at least 10% by weight comprises macrofibers of a lower melting point thermoplastic material to assist the fiber to fiber bonding. In a further embodiment of the invention the macrofibers may be a fiber mixture comprising multi-component macrofibers and a monocomponent macrofiber capable of bonding one with the other.

In another embodiment of the present invention the macrofiber component may be a mix or blend of macrofibers having different properties. For example, a macrofiber mix may comprise two or more different fibers such as a polyester fiber to give the desired bonding and a KEVLAR fiber to give stiffness. The proportion of stiffening fiber to bonding fiber may be varied to provide different properties subject to the requirement that the proportion of bondable fibers is sufficient for the macrofiber structure to provide an open support for the microfibers as hereinafter described.

Some materials, such as, for example, polyphenylene sulphide fibers, aromatic polyamides of the type commercially available under the tradename "APYIEL", and polyimide fibers such as those manufactured by Lenzing AG of Austria, exhibit flame retardant properties or are non-flammable. Such materials can, therefore, impart improved flame or fire resistant properties to manufactured products containing the materials in accordance with the present invention.

Methods of manufacturing such fibers are well known. See, for example, U.S. Patent No. 4,148,103, incorporated herein by reference.

Useful two-component fibers include Type K 54, a sheath/core polyester/polyester material available from Kanebo, Ltd., of Japan and Type TJ04S2, a side-by-side polyester/polyester material and Type TJ04C2, a sheath/core polyester/polyester material, the latter two available from Teijin Ltd., of Japan. Other useful two-component fibers are available under the tradename CELBOND® from Hoescht Celanese Corp., Charlotte, N.C., U.S.A.

The fiber/fiber connectivity in the structures in accordance with the invention is preferably principally between the macrofibers and some of the microfibers at various macrofiber/microfiber contact points. Connectivity may also occur between macrofibers at macrofiber/macrofiber contact points. Further, there may be connectivity between microfibers if a mechanical process such as needling or hydro-entanglement is used.

Batts according to the invention are stabilized by effecting connectivity between microfibers, between macrofibers, or between macrofibers and microfibers. Such connectivity, bonding or linking can be effected by a thermal or chemical process or by a mechanical procedure, such as needling or hydro-entanglement.

Thermal bonding of batts according to the invention can be achieved by utilizing macrofibers that have a component with a lower melting temperature than the material of the microfibers. Under such circumstances the macrofibers will bond to other microfibers at their contact points or, optionally, to other macrofibers at macrofiber/macrofiber contact points.

Bonding between fibers, especially macrofibers, may be effected by use of chemical bonding agents. Certain solid, powdered, gaseous, or liquid bonding agents may cause fiber bonding. In the alternative, there are certain autologous bonding agents which would cause fiber bonding directly through the action of an internal

mediate chemical or physical agent.

Connectivity between microfibers and/or microfibers and macrofibers can be effected by using a needloom according to any of the known needling methods used in the fabric art to cause fibers to intermingle and intertwine with one another. In the alternative, fibers of such a blend or assemblage can be subjected to the impact of high pressure fluid jets. The fluid jets are preferably incident upon the insulator material layer substantially normal to the surface. The fluid is preferably water, in which case there is a pressure drop of from 80 to 100 bar for a jet nozzle diameter of from 120 to 160 microns. Such high pressure jets may be applied to both surfaces of the insulator material, either simultaneously or in succession. These high pressure fluid jets cause the fibers within the assemblage to intermingle and entangle one to another. The amount of kinetic energy applied to the jets controls to some extent, up to a limit, the densification of the batt layer. Also, the speed of passage of the batt under the injectors is unimportant so long as the batt does not move too quickly for entanglement of the fibers to occur. It has been observed that under the appropriate conditions, entanglement of the fibers occurs rapidly and that increased time of exposure to the fluid jets has little, if any, additional effect.

It is within the scope of the invention that the insulating material may be subjected to more than one procedure to cause entanglement and/or bonding between the fibers. For example, a batt comprised of microfibers and macrofibers could first be needled and then the needled batt could be subjected to sufficient heating to cause the macrofiber component to bond with microfibers and macrofibers. Alternatively, a batt with thermally bonded fibers could be needled.

The particular method of achieving fiber connectivity, bonding and/or entanglement is not critical, but must be carried out under conditions such that structural integrity is imparted to the batt without appreciable immobilization of its constituent fibers. It would be appreciated by one skilled in the art that any appreciable change in the macrofibers or microfibers during processing will effect the thermal properties adversely. Therefore, this procedure needs to be conducted to maintain the physical and thermal insulating properties of the fiber components and the assemblage as much as possible.

In a particular embodiment of the present invention bonding within the structure may be effected by heating the assemblage of fibers for a time and at a temperature sufficient to cause the fibers to bond. Such heating may be at a temperature of from about 260°F to 435°F for a period of from about 1 to 10 minutes and preferably at a temperature of from about 285°F to 390°F for a period of from about 3 to 7 minutes. These periods are, of course, dependent upon the material of the macrofiber component.

The microfibers are crimped to assist in the intimate blending and/or in the assemblage of the two fibrous components. Crimping techniques are well known in the art, but the average crimp number is preferably within the range of 8 to 20 crimps per inch. The presence of crimp in the microfibers further assists re-establishment of loft in the fiber assembly after compression or wetting.

In a preferred embodiment the microfibers may have a tensile modulus of from 40 to 90 grams/denier. This relatively high tensile modulus contributes to a high fiber bending modulus and assists with the mechanical performance of the material in accordance with the invention.

The microfibers may be partly or completely slickened with lubricant. Typical lubricants are aqueous solutions of organopolysiloxanes, emulsions of polytetrafluoroethylene and non-ionic surfactants. Such lubricants may be applied to the fibers by spray or dip techniques well known in the art.

The assemblage of macrofibers and microfibers may be a batt consisting of plied card-laps although other fibrous forms such as air-laid webs are equally suitable. Webs and batts in which some fibers are oriented in the through-the-thickness direction as well as in the primary sheet plane may be of distinct advantage from a mechanical performance standpoint. Webs and batts of continuous filaments whether bonded, entangled or otherwise stabilized may be used.

In the following examples where reported the following tests were employed:

Density: The volume of each insulator sample was determined by fixing two planar sample dimensions and then measuring thickness at 0.002 lb/in<sup>2</sup> pressure. The mass of each sample divided by the volume thus obtained is the basis for density values reported herein.

Thickness was measured at 0.002 lb/in<sup>2</sup>.

Apparent thermal conductivity was measured in accord with the plate/sample/plate method described by ASTM Method C518.

Compressional Strain: Strain at 5 lb/in<sup>2</sup>, which was the maximum strain in the compressional recovery test sequence, was recorded for each test.

Compressional Recovery and Work of Compression and Recovery: Section 4.3.2. of Military Specification MIL-B-41826E describes a compressional-recovery test technique for fibrous batting that was adapted for this work. The essential difference between the Military Specification method and the one employed is the lower pressure at which initial thickness and recovered-to-thickness were measured. The measuring pressure in the Specification is 0.01 lb/in<sup>2</sup> whereas 0.002 lb/in<sup>2</sup> was used in this work.

**EXAMPLES****COMPARATIVE EXAMPLES**

Comparative Examples 1 to 4 are commercially available products of 3M (Minnesota Mining and Manufacturing Co.) sold under the tradename THINSULATE®. They are representative of "thin insulators" that are customarily employed whenever trim garment lines and minimal bulk are desired. As has been discussed above, the bending stiffness of this class of insulators is often considered to be undesirably high. Consequently, an alternative material is offered, also by 3M, that is said to be softer and "engineered for use with today's soft drapable outer shell fabrics". Examples of this alternative material, designated by its manufacturer as Type M, are described herein as Comparative Examples 1A, 2A, and 4A.

Physical characteristics of these comparative examples are set forth in Tables I and II below. With regard to Comparative Examples 1A, 2A, and 4A, the Type M materials, only the flexural rigidity values are set forth in Table II. The thermal properties of these samples were not measured since they were assumed to be comparable to those of corresponding Comparative Examples 1, 2, and 4, respectively.

**EXAMPLES 1 and 3**

Examples 1 and 3 were made using a production scale card-line, cross-lapper and bonding-oven combination. For each of these samples, a quantity of 0.5 denier, 7.5 micron diameter, polyester microfiber that had been spun, drawn, cut to a staple length of 1.2 inches, crimped and treated with a polydimethylsiloxane finish was blended with two other fibrous components. One of these additional components was similar to the first in that it was 0.5 denier, 7.5 micron diameter, polyester microfiber that had been spun, drawn, cut to a staple length of 1.2 inches, and crimped; however, this second component was not treated with polydimethylsiloxane finish. Both the first and second fibrous components are available under the designation Type D-716 from Fiber Industries. The third blend component was 4.0 denier, sheath/core, straight (crimpless), binder macrofiber that had been cut to a staple length of 1.5 inches (available under the designation Type K 54 from Kanebo, Ltd.). The blend ratio was 60/18/22, polydimethylsiloxane treated microfiber/non-treated microfiber/binder macrofiber, respectively. From this it can be seen that the overall microfiber/macrofiber ratio was 78/22.

After the fibers were mixed, the resulting fiber blend was carded to form a web, cross-lapped to make a lofty batt consisting of multiple web-layers, and passed through an infrared bonding oven having an air temperature of approximately 350°F. The dwell time in the oven was about two minutes. A continuous transport belt carried the batt from the cross-lapper, through the oven, and into a fixed-height cooling zone that is essential to the process. In the cooling zone, the transport belt passed over, and was in close sliding contact with, a flat, steel, water-cooled platen. Above the water cooled platen was a 6-inch diameter water-cooled roller which could be adjusted vertically. This adjustment was used to vary the roller-to-belt gap to make examples of different thicknesses. All examples exited the oven with a thickness greater than the set-dimension of cooling gap, which compressed each example to its final thicknesses.

**EXAMPLES 2 and 4**

Examples 2 and 4 were made on a hand-sample basis in the laboratory as an expedient to more readily obtaining small samples with precise combinations of thickness and volume density. However, Examples 2 and 4 could have been made using the modified production approach described for Examples 1 and 3, as described above. The laboratory fabrication method employed for Examples 2 and 4 began with lofty batts previously made on the mixing/carding/cross-lapping/bonding production-line previously described. The lofty batts were comprised of the same 60/18/22 fiber blend of Examples 1 and 3, but they had not been subjected to any compression while cooling. Lofty batts having the desired areal density were selected and cut into 12 x 12 inch square samples. These samples were placed and centered on a 16 x 17 x 0.4 inch aluminum plate and aluminum spacer blocks, approximately 1 x 14 inches by the desired final sample thickness, were then placed on the edges of the plate around the sample. A top plate of aluminum measuring 16 x 16 x 0.18 inches was then placed over the assembly, compressing the lofty sample to the thickness fixed by the spacer blocks. The entire assembly was then put into a bench-top, conductive oven that had been pre-heated to 400°F. After 20 minutes the assembly was removed from the oven and allowed to cool for approximately one hour at room temperature. In each case, sample thickness, area and weight measurements then confirmed that thickness and volume density combinations very close to those desired had been obtained.

The physical characteristics of Examples 1 to 4 are set forth in the following tables:

TABLE I.  
THERMAL CONDUCTIVITY AND THERMAL RESISTANCE

	Thickness (inch)	Areal Density (oz/yd <sup>2</sup> )	Volume Density (lb/ft <sup>3</sup> )	Apparent Thermal Conductivity, k (Btu-in/hr-ft <sup>2</sup> -°F)	Thermal Resistance, R (hr-ft <sup>2</sup> -°F/Btu)	Thermal Resistance per Unit Thickness (R/inch)
<b>Example 1</b> Comparative Example 1 (THINSULATE® C100)	0.35	3.42	0.81	0.231	1.52	4.34
<b>Example 2</b> Comparative Example 2 (THINSULATE® C150)	0.34	3.42	0.83	0.255	1.33	3.91
<b>Example 3</b> Comparative Example 3 (THINSULATE® B400)	0.34	12.06	2.95	0.201	1.69	4.97
<b>Example 4</b> Comparative Example 4 (THINSULATE® C200)	0.74	6.54	0.74	0.252	2.93	3.96
	0.74	6.47	0.73	0.282	2.62	3.54

TABLE II.

## FLEXURAL RIGIDITY

	Thickness at 0.002 lb/in <sup>2</sup> (inch)	Areal Density (oz/yd <sup>2</sup> )	Areal Density (g/m <sup>2</sup> )	Volume Density (lb/ft <sup>3</sup> )	Flexural Rigidity/Unit Width*		
					Machine Direction (mq·cm)	Cross Machine (mq·cm)	Geometric Mean (mq·cm)
<b>Example 1</b>	0.35	3.42	116	0.81	141	374	230
Comparative Example 1 (THINSULATE® C100)	0.33	3.42	116	0.86	877	1560	1170
Comparative Example 1A (THINSULATE® M100)	0.28	3.14	106	0.94	934	287	518
<b>Example 2</b>	0.41	4.82	163	0.98	223	288	253
Comparative Example 2 (THINSULATE® C150)	0.44	4.92	167	0.93	1630	2080	1840
Comparative Example 2A (THINSULATE M150)	0.45	4.90	166	0.91	2160	1460	1780
<b>Example 3</b>	0.34	12.06	409	2.95	9400	14,600	11,700
Comparative 3 (THINSULATE® B400)	0.34	12.06	409	2.95	15,300	13,100	14,200
<b>Example 4</b>	0.74	6.54	221	0.74	1380	2200	1740
Comparative Example 4 (THINSULATE® C200)	0.74	6.47	219	0.73	3120	4220	3630
Comparative Example 4A (THINSULATE® M200)	0.55	6.90	234	1.04	5610	6690	6120

\* All flexural rigidity tests made in accordance with ASTM D1388, Option A, Cantilever Test. Each flexural rigidity value shown is the average of 16 determinations. The standard normal specimen pressure for this test is 0.50 lb/in<sup>2</sup>; this was changed to 0.002 lb/in<sup>2</sup> to accommodate the relatively soft insulation samples.



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The thermal resistance and flexural rigidity values from Tables I and II were used to calculate the thermomechanical parameter  $T$ . The calculated values  $T$  and ratios of  $T$  for examples of the invention as compared to comparative samples are set forth in the following table:

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TABLE III.

## VALUES OF THERMOMECHANICAL PARAMETER T

	Thermal Resistance/ Unit Thickness		Flexural Rigidity/Unit Width Geometric Mean		T $\frac{\text{m}^2 \cdot \text{K}}{\text{W} \cdot \text{m}}$  $\text{mN} \cdot \text{cm}$	Ratio  T example T comparison
	(R/inch) <sup>a</sup>	( $\text{m}^2 \cdot \text{K}/\text{W} \cdot \text{m}$ ) <sup>b</sup>	( $\text{mg} \cdot \text{cm}$ ) <sup>c</sup>	( $\text{mN} \cdot \text{cm}$ ) <sup>b</sup>		
<b>Example 1</b> Comparative Example 1 (THINSULATE® C100)	4.34	30.1	230	2.26	13.3	5.64
<b>Example 2</b> Comparative Example 2 (THINSULATE® C150)	3.91	27.2	1170	11.5	2.36	8.50
<b>Example 3</b> Comparative Example 3 (THINSULATE® B400)	4.49	31.1	253	2.48	12.5	1.32
<b>Example 4</b> Comparative Example 4 (THINSULATE® C200)	3.82	26.5	1840	18.0	1.47	2.33
	4.97	34.5	11,700	115	0.300	
	4.53	31.6	14,200	139	0.227	
	3.96	27.6	1740	17.1	1.61	
	3.54	24.6	3630	35.6	0.691	

<sup>a</sup> Values in units as measured, from Table I.<sup>b</sup> Values converted to S.I. units<sup>c</sup> Values in units as measured, from Table II.

In each case the thermomechanical parameter is much higher for the material of this invention than for the equivalent comparative example made using the THINSULATE technology, and inspection of the data of Table III shows that this difference has two components. The thermal resistance of the novel material is slightly better than that of the THINSULATE, as a consequence of the optimization of fiber diameter within the assembly, in accord with the teachings of our previous patent. More significantly, however, the flexural rigidity of the novel material is much less than that of the THINSULATE material, and this is attributable to the greater degree of freedom of motion in a carded assembly of individual staple fibers, as opposed to the high degree of sheet-like unification that is found in the melt-blown assembly. In combination these two factors bring about the wide differentiation between the two materials shown in Table III, and demonstrate the clear superiority of the new materials for apparel and related applications. This superiority can be quantified by computing the ratios of the normalized figures of merit for the two types of material, and these values are also shown in Table III.

The compressional properties of the insulating materials of Example 2 and Comparative Examples 2 and 2A were determined. The results are set forth in the following table:

**TABLE IV.**  
**COMPRESSIONAL PROPERTIES**

	Thickness (inch)	Areal Density (oz/yd <sup>2</sup> )	Volume Density (lb/ft <sup>3</sup> )	Compressional Recovery (%)	Initial Modulus (lb/in <sup>2</sup> )	Work of Compression (lb-in)	Work of Recovery (lb-in)	Resilience (%)
<b>Example 2</b>	0.46	4.76	0.86	95	0.016	0.50	0.34	68
Comparative Example 2 (THINSULATE® C150)	0.44	4.92	0.93	95	0.039	0.98	0.44	45
Comparative Example 2A (THINSULATE® M150)	0.43	4.56	0.88	88	0.044	0.80	0.39	49

- Each value shown is the average of three determinations.
- The end-point of all compression tests was 0.70 lb/in<sup>2</sup>.
- Compressional recovery values based upon original thickness of each sample measured at 0.002 lb/in<sup>2</sup>.

Figure 1 is a compressional stress-strain diagram that further facilitates comparison of the compressional behavior of Example 2 of the invention with Comparative Example 2, commercially known as THINSULATE C150, and with Comparative Example 2A, commercially known as THINSULATE M150. Inspection of the data of Table IV and/or the stress-strain curves of Figure 1 shows that Comparative Examples 2 and 2A have initial moduli that are approximately twice and three times, respectively, that of Example 2. The low modulus of the Example of the invention will be manifest to users as a desirable lack of resistance to compression, or as softness, and is one of the essential attributes of the invention. Further evidence of the desirable tactile characteristics of the invention is apparent in comparisons of the work of compression (the area under the stress-strain curve) for Example 2 with that of Comparative Examples 2 and 2A. Compression of Comparative Example 2 requires approximately twice as much work as Example 2 to achieve the same stress level; Comparative Example 2A requires about 1.6 times the work of Example 2. The much higher resilience value obtained for Example 2 (Table IV), as compared with those for Comparative Examples 2 and 2A, is indicative of a more lively, springy feel when compressed and released. This is another important tactile aspect of the invention.

Figures 2 and 3 are photomicrographs of Example 2, taken with a scanning electron microscope (SEM) at a magnification of 500X and Figures 4 and 5 are similarly obtained photomicrographs of Comparative Example 2 (THINSULATE C150), also at 500X. The significant structural differences between examples of the invention and the comparative examples, which are representative of the previous state of the art, can be readily seen by comparing Figures 2 and 3 with Figures 4 and 5.

The structure of Example 2, as illustrated in Figures 2 and 3, consists of an array of independent, spun and drawn microfibers and macrofibers. The inherent bending elasticity of these fibers, together with the relative mobility of the fibers, provides the softness, the springiness and the drapability that distinguishes the insulator of the subject invention. Fiber mobility was ensured, in the case of Example 2, by judicious selection of binder fiber (macrofiber) type and quantity (as a proportion of the total fiber content), as was mentioned above. In Figures 2 and 3 it can be seen that bonds actually exist at relatively few macrofiber/microfiber and macrofiber/macrofiber contact points. Further, in the case of Example 2, fiber mobility was enhanced by employing a lubricating finish, polydimethylsiloxane, on some of the microfibers, also discussed above. Other embodiments of the invention, whether bonded by other means, needled, hydroentangled or fabricated by some combination of these methods, will be characterized by a minimal number of bonding and/or entangling sites, and, as a consequence, the fibers comprising the structure will be relatively mobile.

Figures 4 and 5, which depict the fibrous structure of Comparative Example 2, make evident a very high degree of fiber interconnectivity. This interconnectivity immobilizes individual fibers and results in a much more unitized, sheet-like structure than the one provided by the subject invention, as illustrated in Figures 2 and 3. The unitized sheet-like structure of Comparative Example 2 results in an insulating material that, in comparison to that of the invention, is stiff in bending, stiff in compression, and has a low value of resilience.

#### EXAMPLE 5

A batt material was manufactured substantially in accordance with the method described in U.S. Patent No. 4,992,327, incorporated herein by reference. The microfiber element was a 0.5 denier polyester blend and the macrofiber element was a 4 denier bi-component polyester. The fiber blend was carded into webs having a lapped base weight of approximately 3 oz/yd<sup>2</sup>, i.e., approximately 6 laps of card web.

Some samples of the batt were subjected to a bonding heat treatment and others were not.

Individual samples were cut from each batt about 1.5 to 2 feet in length and 12 to 14 inches in width.

The experimental machine on which the entanglement was effected comprised an array of jets coupled to a pump capable of providing a pressure drop of up to 90 bar. Nozzle diameter of each jet was 140 microns.

The jets were lowered to within 1/4 inch of the batt surface and the surface was pretreated to be rendered as planar as possible. This pretreatment was achieved by saturating the batt and then compressing it by passing between a metal screen belt and a drum immersed in water before passing under the first injector with its array of nozzles. Three injectors each with an array of nozzles extending across the 14 inch width of each sample was designed to treat the batt in succession. The first injector was operated at a somewhat lower pressure than the last two. The water debouching from the jets was carried away by means of a vacuum slot to collect the water after it passes through the structure. Each vacuum slot was approximately 1/4 inch wide and operated on a vacuum of approximately 15 bar.

The jets impinged on the top surface only of the batt, and after one pass through the machine, the batt was turned over and run under the injectors again so that the jets impinged on the second side of the batt.

The following samples were run:

Sample 1 was single layer of non-heat set material.

Sample 2 was a double layer of non-heat set material.

Sample 3 was a single layer of heat set material.

Sample 1 was found to be comparatively hard to wet out. The fibers stuck to the screen in the saturator and consequently, this was run under the inj ctors without saturation. The resultant fabric layer was a very uniform, strong fabric.

Sample 2 also produced a very uniform strong fabric, with a much increased density over the untangled material.

Sample 3 produced a good strength fabric, but had some surface rippling therein, probably due to the greater resilience of the partially bonded material.

The process resulted in a very uniform product and had relatively high processing speeds.

The resultant product was much more dense than the unentangled batt, had a feel like flannel and exhibited excellent thermal properties.

The material produced was ideally suited for inclusion in gloves, boots and other areas where a non-lofting insulating material or fabric is commonly employed.

The preceding specific embodiments are illustrative of the practice of the invention. It is to be understood, however, that other expedients known to those skilled in the art or disclosed herein, may be employed without departing from the spirit of the invention or the scope of the appended claims.

## Claims

1. A synthetic fiber thermal insulator material in the form of a cohesive fiber structure, which structure comprises an assemblage of:
  - (a) from about 50 to 100% by weight of slickened, spun and drawn, crimped staple polymeric micro-fibers having a diameter of from about 3 to 12 microns;
  - (b) from about 0 to 30% by weight of unslickened, spun and drawn, crimped staple polymeric micro-fibers having a diameter of from about 3 to 12 microns; and
  - (c) from about 0 to 30% by weight of synthetic polymeric macrofibers having a diameter of from about 12 to 50 microns,
 wherein at least some of the fibers are bonded or mechanically interconnected one to another, and wherein the resultant fiber assemblage has a thermomechanical parameter  $T$  greater than about 0.25 ( $m^2 \cdot K / W \cdot m$ )/(mN-cm).
2. The material of Claim 1, wherein the density of the resultant structure is from about 0.5 to 4.0 lb/ft<sup>3</sup>.
3. The material of Claim 1, wherein the material has an apparent thermal conductivity  $k$  measured by the plate-to-plate method according to ASTM C518 with heat flow down of less than 0.5 Btu-in/hr-ft<sup>2</sup>-°F.
4. The material of Claim 1, wherein the microfiber is selected from one or more of polyester, nylon, rayon, acetate, acrylic, modacrylic, polyolefins, spandex, polyaramids, polyimides, fluorocarbons, polybenzimidazols, polyvinylalcohols, polydiacetylenes, polyetherketones, polyimidazols, and phenylene sulphide polymers.
5. The material of Claim 1, wherein the macrofiber is selected from one or more of polyester, nylon, rayon, acetate, acrylic, modacrylic, polyolefins, spandex, polyaramids, polyimides, fluorocarbons, polybenzimidazols, polyvinylalcohols, polydiacetylenes, polyetherketones, polyimidazols, and phenylene sulfide polymers.
6. The material of Claim 1, wherein the macrofiber is selected from one or more of:
  - (i) multi-component fibers having a moiety of facilitate macrofiber to macrofiber bonding;
  - (ii) a fiber mixture in which at least 10% by weight of the macrofibers comprise macrofibers of a low melting point material; and
  - (iii) a fiber mixture comprising multi-component macrofibers and single component macrofibers capable of bonding one with the other.
7. The material of Claim 6, wherein multi-component macrofibers are selected from two-component fibers in a side-by-side construction or a sheath/core construction.

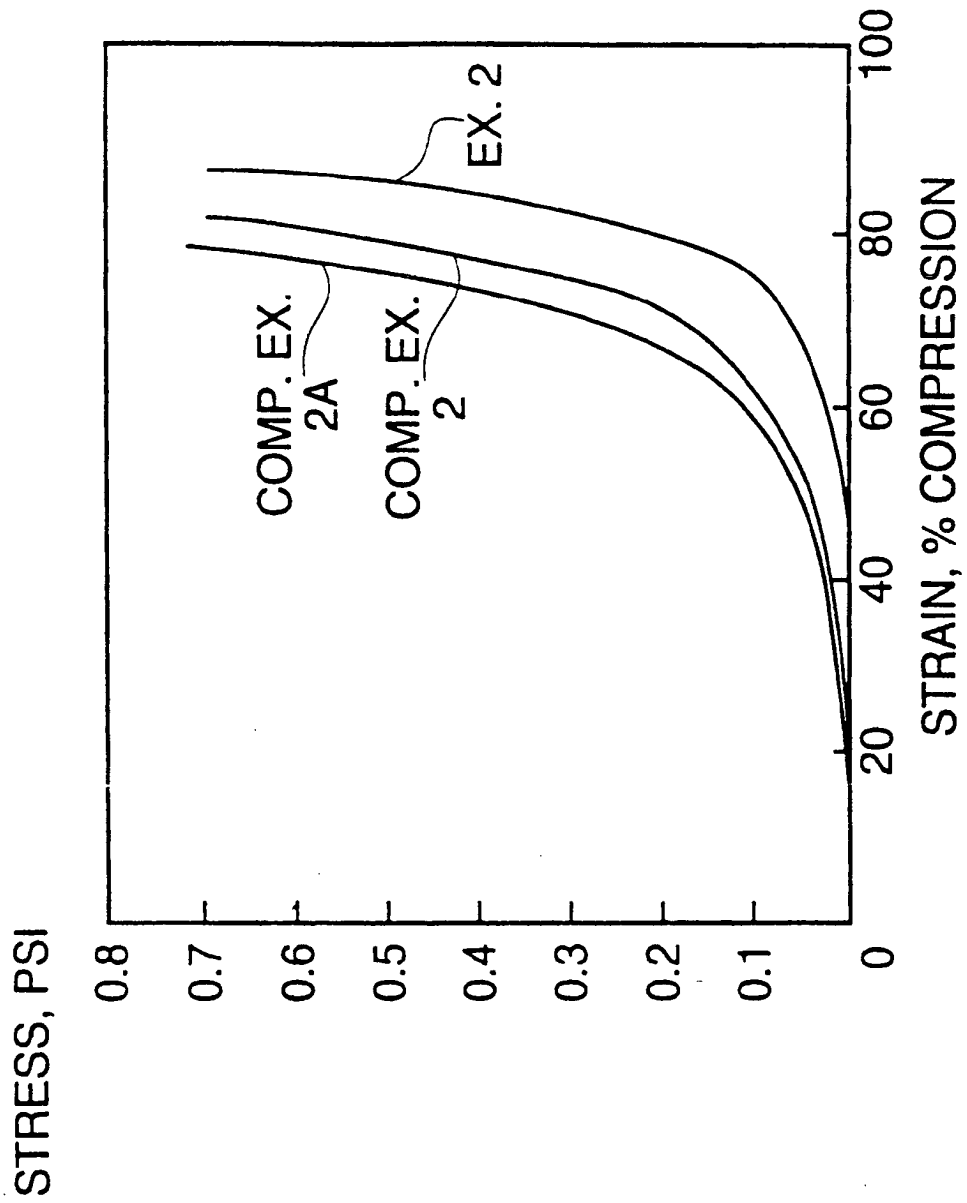


FIG. 1



FIG. 2

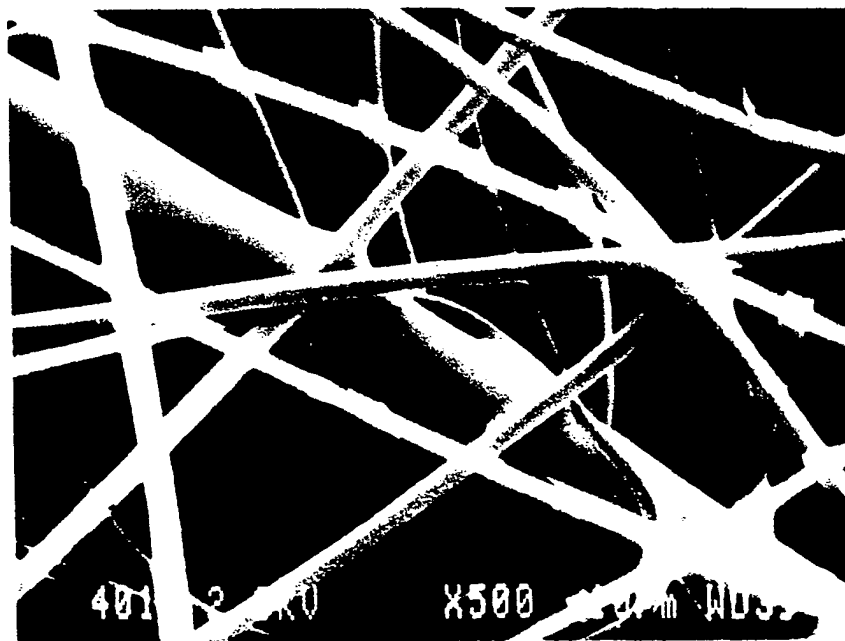


FIG. 3





FIG. 4

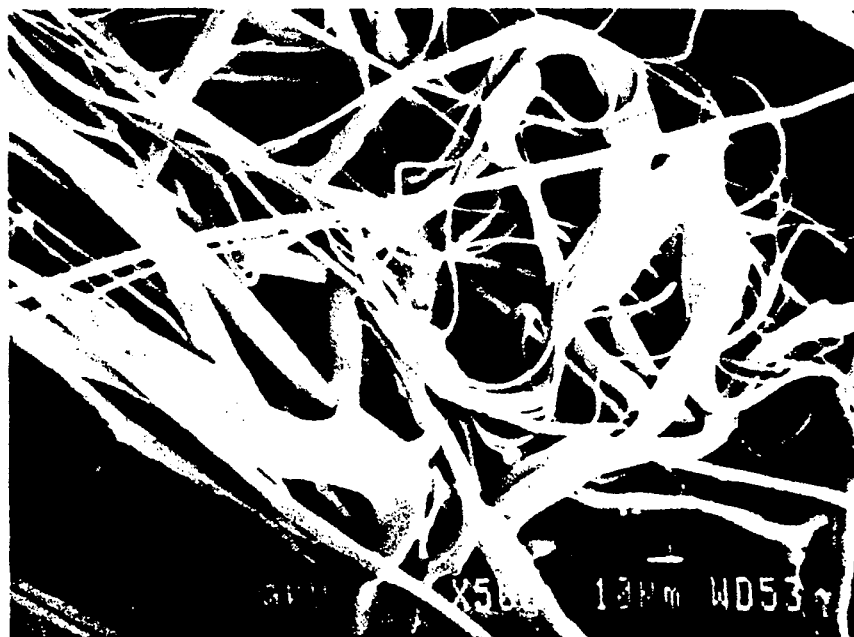


FIG. 5



European Patent  
Office

# EUROPEAN SEARCH REPORT

Application Number  
EP 93 85 0064

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
A	WO-A-80 01031 (E.I. DU PONT DE NEMOURS & COMPANY) * page 8, line 10 - line 18; example 1 *	1,2,4-7	D04H1/54 D04H1/42
D,A	US-A-4 118 531 (HAUSER) * column 5, line 13 - column 7, line 60; examples 1-7 *	1,4,5	
			TECHNICAL FIELDS SEARCHED (Int.Cl.5)
			D04H
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 4 March 1994	Examiner VAN BEURDEN, S
<p><b>CATEGORY OF CITED DOCUMENTS</b></p> <p>X : particularly relevant if taken alone  Y : particularly relevant if combined with another document of the same category  A : technological background  O : non-written disclosure  P : intermediate document</p> <p>T : theory or principle underlying the invention  E : earlier patent document, but published on, or after the filing date  D : document cited in the application  L : document cited for other reasons  &amp; : member of the same patent family, corresponding document</p>			

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